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Modeling the impacts of no-till practice on soil erosion and sediment yield with RUSLE, SEDD, and ArcView GIS

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Abstract

The revised universal soil loss equation (RUSLE), the sediment delivery distributed (SEDD) model, and ArcView GIS were used to estimate the impacts of no-till practice on soil erosion and sediment yield in Pataha Creek Watershed, a typical dryland agricultural watershed in southeastern Washington. The results showed that the average cell soil loss decreased from 11.09 to 3.10 t/ha yr for the whole watershed and from 17.67 to 3.89 t/ha yr for the croplands under the no-till scenario. Likewise, the average cell sediment yield decreased from 4.71 to 1.49 t/ha yr for the entire watershed and from 7.11 to 1.55 t/ha yr for the croplands under no-till practices. The major reason why no-till practice can significantly reduce the soil erosion and sediment yield is that it prevents rill generation which through rill erosion ultimately contributes up to 90% of the soil erosion in the Inland Pacific Northwest region.

Keywords: Soil erosion; Sediment yield; RUSLE; No-tillage practices; Pataha Creek Watershed; ArcView GIS

1. Introduction

Soil erosion is a major environmental problem worldwide. Global water erosion and wind erosion affect 1094 and 549 Mha, respectively (Lal, 2003). In the United States alone an estimated 4 billion tons of soil and 130 billion tons of water are lost from 160 million ha of cropland each year, translating into an on-site economic loss of more than $ 27 billion each year, of which $ 20 billion is for replacement of nutrients and $ 7 billion is for lost water and soil depth (Pimentel et al., 1995). A more specific and primary concern to the Inland Pacific Northwest (IPNW) is the fact that soil erosion leads directly to high levels of stream sedimentation, which has been identified as a main contributor to salmon decline. In Washington State alone, 16 salmon species have been listed as endangered or threatened under the Endangered Species Act. Thus, the ability to reduce the amount of erosion and sediment delivery is essential not only for conservation efforts, but also for salmon habitat restoration.

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No-till farming, due to an associated increase in surface residue and reduction in surface runoff, has been recommended as a best management practice (BMP) for reducing soil erosion. Surface residues affect erosion by decreasing the soil surface area susceptible to raindrop impact, reducing the velocity of runoff water and hence its transport capacity, and by creating mini-ponds that result in deposition behind clumps of residue.

In plot studies at the Palouse Conservation Field Station near Pullman, Washington, it was found that a surface residue cover of 30% reduced erosion to 26% of that when no residue was present (McCool et al., 1997). A 5-year runoff plot study by the University of Idaho showed that soil loss from minimum-till was only 7% that from conventional seeding while no-till was only 10% that from conventional seeding (Dowding et al., 1984). Soil erosion effects on soybean yield conducted by McGregor et al. (1992) showed that soil loss from conventional-till plots during a 60 min rainfall simulation was 62, 34, and 350% greater than that from no-till plots in 1986, 1987, and 1990, respectively. Sturgul et al. (1990) studied the tillage and canopy effects on interrill erosion from first-year alfalfa and observed soil loss reductions of 71–100% from no-till relative to moldboard. Dabney et al. (2000) studied management and subsurface effects on runoff and sediment yield from small watersheds and found that no-till management reduced sediment production by about 90% on plots and by at least 95% on watersheds. At an Ohio watershed, about 6–10 times more sediment resulted from predominantly tilled sub-watersheds than from no-till sub-watersheds (Matisoff et al., 2002). Two rainfall simulation runs with an average rainfall application rate of 70 mm/h were conducted by Lindstrom et al. (1998) to study the effects of tillage systems on water runoff and soil erosion. Their results showed that soil loss from moldboard plowed treatment were 6.7 and 18.2 t/ha for the two runs and only 0.2 t/ha from no-till treatment.

Most of the above mentioned studies are based on experimental data, in which the weather conditions were difficult to control. As a result it is possible that the no-till and conventional fields might have the same amount of soil erosion if the precipitation is really low during a specific season. Thus to avoid this seasonal aspect, soil erosion studies require long-term data to ascertain interannual variability (Lal, 1994). In contrast to experimental plot/watershed, another popular method is to use the soil erosion and delivery model. A modeling approach can give long-term average values if the model input is based on the annual average parameters. Moreover, models can be used to analyze the sensitivity of the parameters and answer the "if–then" questions.

The universal soil loss equation (USLE), a plot or field-scale model, is a widely used program that estimates long-term water erosion from interrill and rill areas (Wischmeier and Smith, 1978). A revised version of this model (RUSLE) further enhanced its capability to predict water erosion by incorporating new information made available through research of the last 40 years (Renard et al., 1997).

The combined use of GIS and erosion models, such as USLE/RUSLE, has been shown to be an effective approach for estimating the magnitude and spatial distribution of erosion (Mitasova et al., 1996; Molnar and Julien, 1998; Millward and Mersey, 1999; Yitayew et al., 1999; Fernandez et al., 2003).

The goal of this research was to: (1) estimate soil loss and the transport of eroded soil to stream channel by RUSLE, SEDD and ArcView GIS, and (2) study the impacts of no-till practices on soil loss and sediment yield.

2. Methods

2.1. Study site

Pataha Creek Watershed is located in southeastern Washington State and covers an area of about 479 km^2. However, only the upper portion of the Pataha Creek Watershed with a gauge station located at Marengo Station was studied in this paper. The research area is about 327 km^2 with non-irrigated cropland comprising the dominant land use. Winter wheat (*Triticum aestivum*), spring wheat (*T. aestivum*), barley (*Hordeum vulgare*) and peas (*Pisum sativa*) are the major crops grown. Precipitation in the Pataha Creek Watershed is unevenly distributed both in time and in space. The majority of precipitation occurs between September and May, or during the winter, with approximately 30% of it falling as snow. Precipitation amounts range from more than 1000 mm a year in the higher elevations of the forested area to about 250–400 mm a year in lower elevations. The elevation is about 470 m at Marengo in the lowlands and about 1700 m at the upper boundary of the watershed. The Pataha Creek meanders through the southern half of Garfield County, beginning in the Umatilla National Forest and ending where it flows into the Tucannon River, a major salmon spawning site. It is the high level of sediment coming in particular from cropland in the watershed that has been identified as the main problem associated with fish habitat and water quality deterioration in the lower Tucannon.

The reasons why Pataha Creek Watershed was chosen include the facts that: (1) the Pataha Creek Watershed is a typical agricultural watershed within the IPNW region; (2) there are high value fish resources in the Tucannon River and Pataha Creek Watershed, as the largest sub-watershed in the Tucannon watershed, has been identified as one of the primary contributors of sediment within the Tucannon River; (3) the Pataha Creek Watershed has been selected as a ‘‘model watershed’’ by the Northwest Power Planning Council and the Bonneville Power Administration which together have made a focused effort to improve upon the upland conservation practices needed to reduce sedimentation (Bartels, 2000); (4) the lower portion of the Pataha Creek could eventually develop into a spawning and rearing habitat for Chinook salmon if some migration barriers are removed and habitat is restored; and (5) the government, decision-makers, and public are interested and concerned about how effective no-till practice really is in this region.

2.2. Soil erosion prediction by RUSLE

Five major factors (rainfall pattern, soil type, topography, crop system, and management practices) are used in USLE/RUSLE for computing the average annual erosion expected on the field slopes and are represented in the equation (Renard et al., 1997):

$$A = RKLSCP \tag{1}$$

where A is the computed spatial average soil loss and temporal average soil loss per unit area (t/ha yr), R the rainfall-runoff erosivity factor (MJ mm/(ha h yr)), K the soil erodibility factor (t ha h/(ha MJ mm)), L the slope-length factor, S the slope steepness factor, C the cover management factor, and P the conservation support practice factor. L, S, C, and P are all dimensionless.

In the application of RUSLE on GIS environment, soil loss is estimated within raster/grid GIS. Raster models are cell-based representations of map features, which offer analytical capabilities for continuous data and allow fast processing of map layer overlay operations (ESRI, 1996; Fernandez et al., 2003). In a raster GIS, the mean annual gross soil erosion is calculated at a cell level as the product of six factors

$$A_i = R_i K_i L_i S_i C_i P_i \tag{2}$$

where the subscript i represents the ith cell.

2.2.1. Rain-runoff erosivity factor (R)

An equivalent R factor (R_{eq}) has been developed for the unique climatic conditions of the IPNW region which features a winter rainy season and cyclic freezing and thawing of soil (USDA-ARS, 2002). It is related to the annual precipitation (P_r, mm) in a linear relationship:

$$R_{eq} = -823.8 + 5.213 P_r \tag{3}$$

The precipitation spatial distribution for Pataha Creek Watershed was clipped from the precipitation map for Washington State, which is available at http://www.ftw.nrcs.usda.gov/prism/prismdata_state.thml and was verified using precipitation from an existing weather station at Pomeroy, WA, USA, a town within Pataha watershed. A lack of existing climate data for the site being studied forced the use of this alternative method. This may be of lower scientific value, but it is a useful approach for dealing with no-data situations.

2.2.2. Soil erodibility factor (K)

The K factor is an empirical measure of soil erodibility as affected by intrinsic soil properties. The main soil properties affecting K are soil texture, organic matter, structure, and permeability of the soil profile. K values have been estimated for all the vertical layers of the soil series surveyed by the Natural Resource Conservation Service (NRCS) and are included in the attribute data file of soil maps (in 7.5 min quadrangle units, scale 1:24,000) in the Soil Survey Geographic (SSURGO) database (http://www.ftw.nrcs.usda.gov/ssur_data.html). In SSURGO, K values are expressed as annual averages in English units, which were converted to SI metric units according to Foster et al. (1981).

The Pataha Creek Watershed is located in the Garfield County, WA623 sheet of the SSURGO database. There are 106 different soil types (codes) at WA623, but the K only has four different values, which are 0.042, 0.049, 0.057, and 0.065 in SI units.

2.2.3. Slope-length (L) and slope steepness (S) factors

The L and S factors in RUSLE reflect the effect of topography on erosion. There are a number of empirical formulas capable of calculating the L and S factors. For example, Yitayew et al. (1999) computed slope steepness and length factors (LS) with GIS by using four different methods. The first two approaches used vector data input while the third and fourth used raster data input. Choosing a suitable algorithm among those available was ultimately dependent upon the characteristics of the particular watershed. A formula developed by McCool et al. (1987, 1993) to estimate S factor, which is more suitable to the IPNW than other formulas, was ultimately adopted in this study. The formula is

$$S = \begin{cases} 10.8\sin\theta + 0.03, & s < 9\%, \\ \left(\dfrac{\sin\theta}{0.0896}\right)^{0.6}, & s \geq 9\% \end{cases} \tag{4}$$

where S is the RUSLE factor, θ the slope angle (°), and s the steepness (%). The slope is usually in the degree format not percentage format when it is derived from DEM via GIS software.

The following formula to calculate the L factor in GIS environment developed from Desmet and Govers (1996) was adopted in this study

$$L = (m+1)\left(\frac{U_{i,j\,\text{out}} + U_{i,j\,\text{in}}}{2\times 22.13}\right)^m = (m+1)\left(\frac{2U_{i,j\,\text{in}} + b}{2\times 22.13}\right)^m \tag{5}$$

where $U_{i,j\ \text{in}}$ is the upslope contributing area per unit contour width at the inlet of a grid cell, $U_{i,j\ \text{out}}$ the upslope contributing area per unit contour width at the outlet of the grid cell, and $U_{i,j\ \text{out}} = U_{i,j\ \text{in}}$ + (cell area)/$b = U_{i,j\ \text{in}} + b$ (b is the cell resolution). Additionally, m is the slope-length exponent with $m = 0.5$ for the IPNW region (McCool et al., 1993) and $m = 0.4$–0.6 having been suggested for other areas (Moore and Wilson, 1992).

Generally, $U_{i,j\ \text{in}}$ is taken as the sum of the grid cells from which water flows into the cell of interest (Mitasova et al., 1996):

$$U_{i,j\,\text{in}} = \frac{1}{b}\sum_{i=1}^{n_i}\mu_i a_i \tag{6}$$

where a_i is the area of cell i, n_i the number of cells draining into the cells, μ_i the weight depending on the runoff and infiltration rates of individual cells, and b the contour width approximately by the cell resolutions.

If $\mu_i = 1$ and $a_i = b^2$, then $U_{i,j\ \text{in}}$ becomes $n_i b$ (Mitasova et al., 1996; Fernandez et al., 2003), which is flow accumulation multiplied by the cell resolution.

Surface runoff will usually concentrate in less than 400 ft (122 m), which is a practical slope-length limit in many situations, although longer slope-lengths of up to 1000 ft (305 m) are occasionally found (McCool et al., 1997). Accordingly, a slope-length limit should be imposed to appropriately represent the interrill and rill erosion processes in erosion modeling (Fernandez et al., 2003). This limit was set as 120 m in this study based on this statement and actual topographical characteristics.

The 10 m DEM for Pataha Creek Watershed was downloaded from the following website: http://duff.geology.washington.edu/data/raster/tenmeter/. Formulas (4) and (5) were then used to obtain the S and L factors.

The average S factor for Pataha Creek Watershed was about 1.39 with a range from 0.03 to 3.72. The average L factor for the Pataha Creek Watershed was 1.99. Estimation of the S and L factors was the primary role of the GIS for soil erosion application.

2.2.4. Cover management factor (C)

The C factor reflects the effect of cropping and management practice on erosion rate, and is the factor used most often to compare the relative impacts of management options on conservation plans (Renard et al., 1997). The C factor has a close linkage to land use types. The major land use types at Pataha Creek Watershed are: cropland and pasture (58.0%), evergreen forest (18.5%), and mixed rangeland (22.7%).

Table 1
C factor for cropland at Pataha Creek Watershed

Precipitation zone	Practice	Crop rotation	*C* factor	Current status	No-till
H	C	WF	0.1550		
H	N	SW	0.0052		
H	N	WBF	0.0220	0.1019	0.0136
H	R	SW	0.0206		
H	R	WBF	0.1114		
ID	C	WF	0.1452		
ID	N	WBF	0.0309	0.1075	0.0309
ID	R	WBF	0.0997		
IW	C	WF	0.1590		
IW	N	WBF	0.0289	0.1260	0.0289
IW	R	WBF	0.1566		
L	C	WF	0.1148		
L	N	WBF	0.0190	0.0875	0.0190
L	R	WBF	0.0982		

Precipitation zones: H, high precipitation zone; ID, intermediate dry precipitation zone; IW, intermediate wet precipitation zone; L, low precipitation zone. Practice: C, conventional; R, reduced; N, no-till or low-till. Crop rotation: WF, wheat-fallow; SW, spring grain-wheat; WBF, wheat (barley)-fallow.

The *C* factor for cropland is calculated primarily from information on crop rotations obtained using the RUSLE computer program (version SWCS1.06b Win32, USDA-ARS, 2002). The calculated results of the *C* factors for cropland at Pataha Creek Watershed are shown in Table 1. The *C* factor is determined not only by crop rotation, but also by land use practice and precipitation zones. For the present land use pattern, we used 25% for no-till, 20% for reduced, and 55% for conventional. This ratio was estimated by field trips and personal communications with local growers and officers in the Pomeroy Conservation District.

Values of the *C* factor for other land uses such as rangeland and forest are available from the literature (Haan et al., 1994), and are generally lower than those values for croplands with some exceptions, such as bare lands. The *C* factor for various land uses used in this research are summarized in Table 2.

2.2.5. Support practice factor (P)

The *P* factor is the ratio between soil loss with a specific support practice and the corresponding loss with upslope and downslope tillage. These practices principally affect erosion by modifying the flow pattern, grade, or direction of surface runoff and by

Table 2
C factor for different land uses of Pataha Creek Watershed

Code	Land use description	Conventional	No-tillage	Present status
11	Residential	0.0030	0.0030	0.0030
12	Commercial services	0.0050	0.0050	0.0050
13	Industrial	0.0050	0.0050	0.0050
16	Mixed urban or built-up land	0.0040	0.0040	0.0040
17	Other urban or built-up land	0.0040	0.0040	0.0040
33	Mixed rangeland	0.0110	0.0110	0.0110
42	Evergreen forest land	0.0010	0.0010	0.0010
75	Strip mines, quarries, and gravel pits	1.0000	1.0000	1.0000
211	Cropland and pasture HP	0.1550	0.0136	0.1019
212	Cropland and pasture IW	0.1452	0.0309	0.1075
213	Cropland and pasture ID	0.1590	0.0289	0.1260
214	Cropland and pasture LP	0.1148	0.0190	0.0875

reducing the amount and rate of runoff (Renard and Foster, 1983). For cropland, the support practices considered included contouring, strip-cropping, terracing, and subsurface drainage (Renard et al., 1997). For Pataha Creek Watershed, there is no significant support practice, so we took P factor to be equal to 1.

2.3. Sediment delivery distributed (SEDD) model

The ratio of sediment delivered to the stream channel to the total soil loss/erosion within the watershed was used in this research, as our main concern was how much eroded soil was delivered into the channel. This means channel erosion and delivery process were not included in this study. The magnitude of the sediment delivery ratio (SDR) for a particular watershed will be influenced by a wide range of geomorphological, hydrological, environmental, and watershed factors. Models capable of calculating SDR can be grouped into two major categories. The first category consists of models derived from statistical analysis of data that relate sediment yield to watershed and climate parameters. The modified USLE (Williams, 1975) is a typical example (Khanbilvardi and Rogowski, 1984). The second category, called the parametric, deterministic, or physically based model, assigns actual numerical values to coefficients that quantify soil detachment as well as sediment transport and deposition. Models within this category are those developed by Foster and Meyer (1972), Khanbilvardi et al. (1983), and the Water Erosion Prediction Project (WEPP) (Huang and Bradford, 1993).

The sediment delivery ratio for cell i, SDR_i, meaning the fraction of the gross soil loss from cell i that actually reaches a continuous stream system, was estimated following Ferro and Minacapilli (1995) and Ferro (1997) as a function of travel time:

$$\mathrm{SDR}_i = \exp(-\beta t_i) \tag{7}$$

where t_i is the travel time (h) for cell i to the nearest channel cell and β is a watershed-specific parameter. The time for runoff water to travel from one point to another in a watershed is determined by the flow distance and velocity along the flow path (SCS-TR-55, 1975; Bao et al., 1997). If the flow path from cell i to the nearest channel traverses N_p cells, then the travel time from that cell is calculated by adding the travel time for each of the N_p cells located along the flow path (Jain and Kothyari, 2000)

$$t_i = \sum_{i=1}^{N_p} \frac{l_i}{v_i} \tag{8}$$

where l_i is the length of segment i in the flow path (m) and is equal to the length of the side or diagonal of a cell depending on the flow direction in the cell, and v_i the flow velocity for the cell (m/s).

There are quite a number of methods used to calculate flow velocity. One of the popular methods is derived from Manning's equation with the form of

$$v_i = k_i s_i^{1/2} \tag{9}$$

where s_i is the slope of cell i (m/m) and k_i is a coefficient for cell i dependent on land cover with the effect measured by the value of Manning's roughness coefficient and hydraulic radius (McCuen, 1998). The k values are available in most hydrological books. To ensure the proper use of formula (8), a lower limit of velocity for the watershed is generally established by setting the minimum cell slope to a small value (e.g., 0.3% in this study) (Smith and Maidment, 1995; Fernandez et al., 2003).

The watershed-specific parameter β depends primarily on watershed morphological data (Ferro, 1997). Fernandez et al. (2003) estimated β with inverse modeling. Jain and Kothyari (2000) tested the β between 0.1 and 1.6 with an increment of 0.1 and found sediment yield is not very sensitive to the value of β used. However, we tested β between 0.5 and 2.0 with an increment of 0.1 and found that the sediment delivery ratio was very sensitive to the values of β, varying from 0.60 ($\beta = 0.5$) to 0.27 ($\beta = 2.0$). In the end, we took $\beta = 1$ in this study.

3. Results and discussions

3.1. Soil loss

The average soil erosion under present land use in the Pataha Creek Watershed predicted by RUSLE was 11.09 t/ha yr, corresponding to 17.67 t/ha yr for croplands, 3.10 t/ha yr for rangeland, and 0.64 t/ha yr for forestlands. The average soil loss intensity of cropland was about 5.7 times that of rangeland,

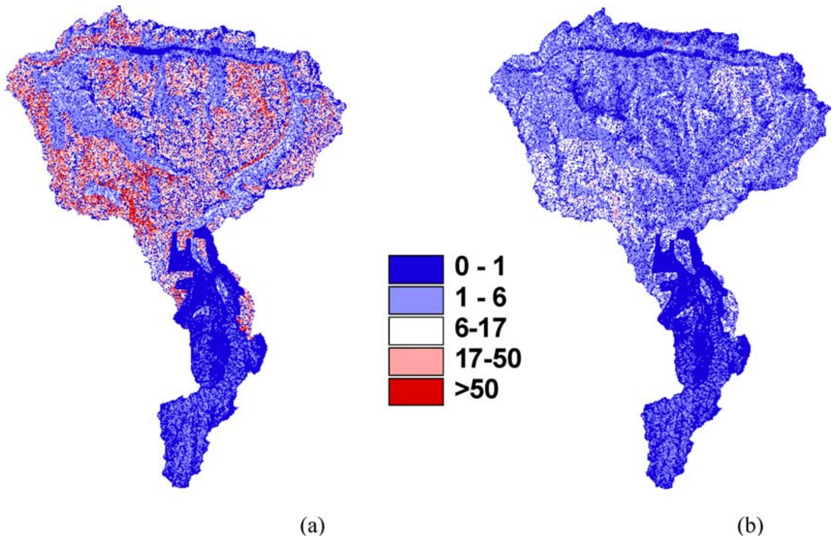

Fig. 1. Soil loss at Pataha Creek Watershed (t/ha yr): (a) current agricultural practices; (b) no-till practices.

and 27.5 times that of forested land. There was a very small portion of strip mine land use (about 0.013%), and its soil loss was as high as 125.66 t/ha yr. The spatial distribution of the gross soil erosion, shown in Fig. 1a, was divided into five categories: Category 1, very low erosion (0–1 t/ha yr); Category 2, low erosion (1–6 t/ha yr); Category 3, moderate erosion (6–17 t/ha yr); Category 4, high erosion (17–50 t/ha yr); and Category 5, very high erosion (>50 t/ha yr).

Category 1 included mostly forested areas located at the higher elevations in the upper Pataha Creek Watershed. These areas accounted for 37.6% of the entire watershed, but the RUSLE-predicted soil loss accounted for only 0.75% of the total.

Category 2 consisted of the valley zone along the stream channel covered mainly by grass and brush and some forested areas. Urban land use, such as residential, commercial service, and industrial land also fell into this category. This category accounted for 20.1% of the total area but only contributed to 6.0% of the total soil loss.

Category 3 did not have an obvious geographic region. This moderate erosion category occupied 15.7% of the watershed with an equivalent 15.4% of the total soil loss.

Category 4 included most of the agricultural zones of the watershed. This category was the major source of soil loss in the watershed. The area of this category was about 20.6% of the whole watershed and soil loss accounted for 55.6% of the totals.

Category 5, the serious soil loss category, included high-erosion agricultural land and the mines. The area of this category was about 4.0% of the whole watershed and soil loss accounted for 22.2% of the totals.

Clearly, agricultural land was the major source of erosion. The agricultural land occupies about 58% of the Pataha Creek Watershed but contributed about 92.4% of the total soil loss in the watershed. Contrastingly, the 22.65% of rangeland only produced 6.3% of the soil loss and the 18.53% of forested land accounted for only 1.1% of the soil loss in the watershed (Table 3).

3.2. Sediment delivery ratio

The SDR spatial distribution (Fig. 2) showed a relationship between the cell distance and the nearest

Table 3
Soil losses by different land use type at Pataha Creek Watershed

Land use type	Area (%)	Soil loss (%)
Urban or built-up land	0.81	0.04
Agricultural land	57.99	92.4
Rangeland	22.65	6.34
Forest land	18.53	1.07
Barren land	0.01	0.15

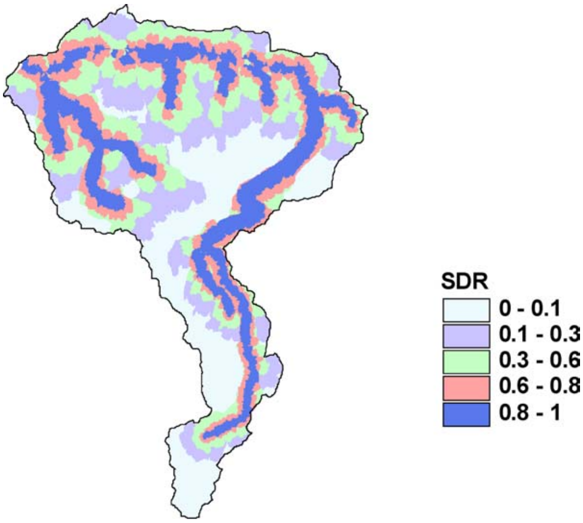

Fig. 2. Sediment delivery ratio at Pataha Creek Watershed.

channel. This is easily explained by formula (8), which assumes that SDR has an inverse relationship with travel time, which is a function of travel length and velocity. Therefore, the same distance does not imply that they will have the same SDR because they may have different travel times due to surface roughness and overland slope. The SDR spatial distribution is very important for identifying the critical sediment source and delivery areas as well as soil erosion control and resource management. Dai and Tan (1996) noted that the SDR values implied the integrated capability of a watershed for storing and transporting the eroded soil.

Unlike soil loss, the SDR_i values obtained for the Pataha Creek Watershed did not exhibit a clear relation with land uses (Fig. 2). This result may be explained by the argument that SDR tends to be affected more by the character of the drainage system than by land uses (Novotny and Chesters, 1989). However, different land use types show distinctness in average SDR (Table 4). This might be because the different land uses have different roughness and distribute at specific locations, with the latter producing different overland slopes and distances to stream channel. The urban or built-up land had the highest SDR (0.892) while the forested land had the lowest SDR (0.356). The SDR average for all grid cells in the Pataha Creek Watershed was 0.437.

3.3. Sediment yield

The average annual sediment yield to the stream channel for the Pataha Creek Watershed, calculated as an average of the sediment yields from all the cells to its nearest channel cell, was 4.71 t/ha yr, or about 42.4% of the total soil loss. Channel erosion and delivery process was not included in this study. The spatial variation (Fig. 3a) of the sediment yield in the entire watershed had roughly the same pattern as soil loss, but was modified with the SDR.

The sources of sediment came from agricultural land. About 87.4% of the sediments reaching the channel were produced in the croplands (Table 4). This means that agricultural land was still the most important area producing sediment yield in the Pataha Creek Watershed. The average sediment yield to river channel at agricultural land was 7.11 t/ha yr, or about 1.5 times that of the watershed average value.

The second important source of sediment yield to the channel was rangeland. It contributed about 11.4% of the entire sediment yield with an average of 2.35 t/ha yr, though its soil loss accounted for about 6.3% of the whole watershed. This might be explained by the fact that it is located near the stream channel and the fact that it has steeper slopes.

The contributions from barren land and urban or built-up area were limited due to their relative smaller areas, even given the fact that barren land had the

Table 4
Soil loss, sediment yield, and SDR for different land use types

Land use type	Soil loss (t/ha yr)	Sediment yield (t/ha yr)	SDR	Sediment yield (%)
Urban or built-up land	0.496	0.442	0.892	0.08
Agricultural land	17.666	7.114	0.402	87.41
Rangeland	3.103	2.348	0.757	11.38
Forest land	0.643	0.223	0.356	0.88
Barren land	125.656	91.005	0.724	0.26

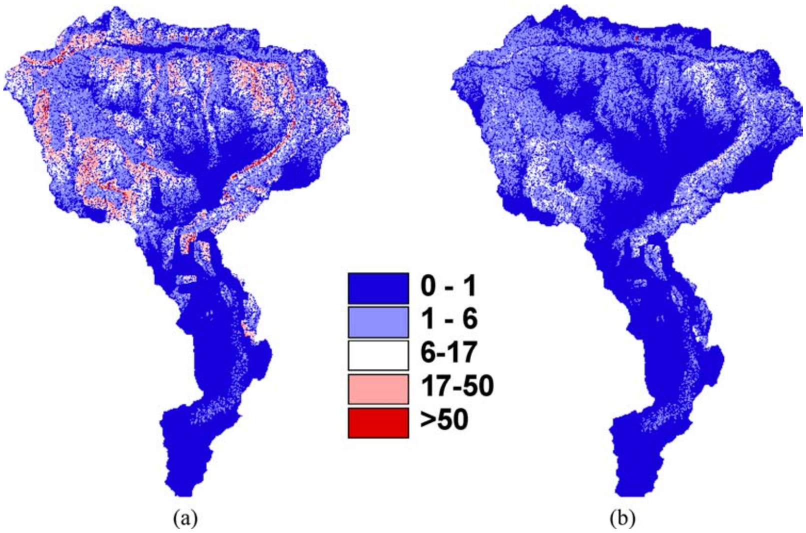

Fig. 3. Sediment yield at Pataha Creek Watershed (t/ha yr): (a) current agricultural practices; (b) no-till practices.

largest soil loss rate and urban or built-up had the largest SDR.

Lastly, the forested land in the Pataha Creek Watershed produced only 0.88% of the sediment yield to the stream channel with its 18.53% area share.

3.4. Impacts of no-tillage practice on soil loss and sediment yield

The results of our RUSLE simulation for a scenario of applying no-till practices to all agricultural land showed that soil loss and soil sediment yield for cropland was dramatically reduced. The soil loss for the whole watershed decreased from 11.09 to 3.10 and 17.67 to 3.89 t/ha yr for croplands (Fig. 1). The average soil loss for each 10 m × 10 m cell was reduced 78.0% for cropland and its contributions to soil loss for the whole watershed decreased from 92.4 to 72.8%. The ratios of soil loss from cropland to rangeland decreased from 5.7 to 1.25, indicating that soil loss from cropland was only about 1.25 times that of rangeland under the no-till practice scenario.

In order to see the impacts of no-till practice, the same categories for soil loss were used. The area of Category 2 (low erosion with soil loss 1–6 t/ha yr) doubled, the area of Category 4 (high erosion with soil loss 17–50 t/ha yr) decreased by 96.5%, and the area of Category 5 (very high erosion with soil loss larger than 50 t/ha yr) almost disappeared (Fig. 1b and Table 5).

The sediment yield also decreased with decline of soil loss. The average sediment yield to stream channel decreased from 4.71 to 1.49 t/ha yr (Fig. 3b) while the sediment yield for cropland decreased from 7.11 to 1.55 t/ha yr (Table 6). The impacts of no-till practices are clearly seen as very significant when the two figures in Fig. 3 are compared. Further more, in this scenario the sediment yield to river channel from cropland was less than that in the rangeland, though the range and stand deviation of sediment yield for

Table 5
Impacts of no-till on soil loss category

Scenario	Soil loss category	0–1 t/ha yr	1–6 t/ha yr	6–17 t/ha yr	17–50 t/ha yr	>50 t/ha yr
Current	Area (%)	37.65	22.06	15.66	20.63	3.99
	Soil loss (%)	0.75	6.05	15.44	55.61	22.15
No-till	Area (%)	40.17	42.94	16.15	0.73	0.01
	Soil loss (%)	2.66	44.45	47.91	4.46	0.53

Table 6
Soil loss and sediment yield by land use type after no-till

Land use type	Soil loss (t/ha)	Sediment yield (t/ha)	Soil loss (%)	Sediment yield (%)
Urban or built-up land	0.496	0.442	0.13	0.24
Agricultural land	3.889	1.546	72.8	60.14
Rangeland	3.103	2.348	22.69	36.01
Forest land	0.643	0.223	3.84	2.78
Barren land	125.656	91.005	0.54	0.82

cropland were still larger than those for rangeland. The sediment yield from cropland accounted for 60.1% of the entire watershed making it almost the same as its area percentage (58%).

3.5. Justification of model results

The model result of this study is that no-tillage significantly reduces soil erosion and sediment input into the river. The challenge, however, is how to validate the model output, because it is extremely difficult, if not impossible, to force all of the farms in the watershed to use no-till practice, which usually results in the decrease of grain yield, especially during the beginning years. Also complicating the matter is the fact that ideally we need long-term experimental data to draw a conclusion. Because of these complications, the validation process is best accomplished through a detailed explanation of the innovative processes/methodologies that were used as well as a comparison of the effectiveness of these processes to existing research results.

The key part of this study is the estimation of the *C* factor, especially the *C* factor for cropland under no-tillage practice. It is consistent with the physical meaning of *C* factor in that it reflects the effect of cropping and management practice on erosion rate and is most often used as a factor to compare the relative impacts of management options on conservation plans, such as no-tillage practices (Renard et al., 1997). The *C* factor for cropland is obtained by running the RUSLE computer program (version SWCS1.06b) based on practical crop rotations in the Pataha Creek Watershed. The assumption is that crop rotations remain the same as the current scenario.

One major reason why the *C* factor for cropland is significantly reduced under no-tillage practice is that rill erosion contributes 90% of the soil erosion in the IPNW and no-tillage practice can significantly prevent the formation of rills. Rill generation experiments, conducted on the Palouse Conservation Field Station (PCFS) of the USDA Agricultural Research Service, located 3 km northwest of Pullman, WA, USA, showed that the no-tillage field had a considerably fewer number of rills than the conventional field when they received the same amount of flow (Mancilla et al., 2005). When the flow applied was about 22.7 l/min, there was no rill formed in the no-tillage field, but there were 1.64 rills every meter (Table 7) in the conventional seedbed field. With the flow larger than 30.3 l/min, there were rills formed in the no-tillage fields, but this precipitation intensity is almost impossible in IPNW region.

Another reason is that no-tillage practice can increase the saturated hydraulic conductivity and result in higher infiltration. Miller et al. (1999) found that saturated hydraulic conductivity for conventional tillage was reduced by a factor of 10 when compared to no-tillage fields. Benjamin (1993) found this same

Table 7
Rill formation from different land treatments (Mancilla et al., 2005)

Treatment	Flow applied (l/min)	Number of rills: average every meter	Tukey's test categories ($\alpha = 0.05$)
MP	15.1	0.55	a
ChP	15.1	0.41	a
NT	15.1	0	a
CT	15.1	1.37	b
MP	22.7	0.96	a
ChP	22.7	0.68	a
NT	22.7	0	b
CT	22.7	1.64	c
MP	30.3	0.96	a
ChP	30.3	0.68	a
NT	30.3	0.41	a
CT	30.3	1.64	b

MP: moldboard plow primary tillage; ChP: chisel plow primary tillage; NT: no-tillage stubble; CT: conventional seedbed tillage.

relationship but at a factor of 2. Our experimental data (Martin, 2002) showed that the saturated hydraulic conductivity in the conventional field was approximately 5.5 times less than the long-time no-tillage field and only half that of the short-term no-tillage field, where field capacity and porosity were very similar for all three treatments.

The model results of this study are consistent with other aforementioned studies. Our model results indicate that no-tillage can reduce soil erosion 78% for cropland and 72.0% for the whole watershed and sediment yield 78.2% for cropland and 68.4% for the whole watershed. Razavian (1990) showed that minimum tillage and no-till systems reduced the sediment yield by about 60 and 80%, respectively, for an agricultural watershed in southwest Nebraska, USA. Dabney et al. (2000) found that no-till management reduced sediment production by about 90% on plots and by at least 95% on watersheds. On small watersheds (2–3 ha) in north Mississippi, annual sediment yield ranged up to about 30 t/ha for conventional tillage soybean with buffer strips and grassed waterways but, after the first year, never exceeded 1 t/ha for no-till soybean (Meyer et al., 1999). Many plot-scale studies (McCool et al., 1997; Dowding et al., 1984; McGregor et al., 1992; Sturgul et al., 1990; Matisoff et al., 2002; Lindstrom et al., 1998) also gave similar results.

4. Conclusions

The coupling of GIS and soil erosion/sediment yield models is an efficient procedure for determining the spatial distribution of soil erosion and sediment yield under a variety of simulation scenarios.

In the case study at Pataha Creek Watershed, the croplands exhibited much greater erosion rates and sediment yield to the stream channel than the non-cultivated lands. They contributed 92.4% of the total soil loss and 87.4% of the entire sediment yield, while only accounting for about 58% of the total area.

No-tillage systems have been considered an effective practice for erosion control. Our model supported this theory by determining that a reduction in soil loss and sediment yield of up to 78.0 and 78.2% could be expected in the Pataha Creek Watershed cropland when no-till practices are implemented.

The key part of this study is estimation of the *C* factor, which is done by running the RUSLE computer program. One major reason why the *C* factor can be significantly reduced by no-tillage practice is that no-tillage practice prevents rill generation and rill erosion which has been known to contribute to 90% of soil erosion in the IPNW region.

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